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Arlan L. Langmaid
The University of Montana

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Evolutionary Change As a Theme For a High School Biology Course: A Literature Review and Thematic Unit

By

Arlan L. Langmaid

A.B. Oberlin College, 1984

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Abstract

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Evolutionary Change as a Theme for a High School Biology Course

Director: Carol A. Brewer, Ph.D. Carol Brewer

Evolution has proven to be a problematic topic for high school students and their teachers for cultural and intellectual reasons. Despite the widely accepted central role evolution plays in understanding biology, recent attempts to remove evolutionary topics from the curricula in several states has superseded an earlier movement to ban the teaching of evolution altogether. To address this issue several national science organizations have continued to emphasize the importance of an understanding of evolution as vital to the comprehension of biology. Many studies suggest that evolution should be the focus of all activities in any biology course. In this study at St. Johnsbury Academy, in Vermont, I attempted such an approach. Pre- and post-test surveys were utilized to determine student understanding of evolutionary concepts and connections to other topics in a year long biology course. The overall trend showed an increase in understanding of evolutionary concepts. Data from Likert and short answer questions were analyzed to assess changes in student understanding. I hypothesized that a thematic approach would result in significant increases in student understanding. Student responses in several categories showed significant increases and most responses were somewhat higher. While much work remains to be done on the problem of student understanding of evolution, the data presented here can provide additional information for future research and improvement in the teaching of evolution within the high school biology curriculum.

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Table of Contents

List of Tables

Table Page

Chapter 1

EVOLUTION IN THE CLASSROOM TODAY-A LITERATURE REVIEW

The theme of evolution is the cornerstone of modern biology. In the often quoted words of Theodosius Dobzhansky (1973): "Nothing in biology makes sense except in light of evolution". While evolution is the central theme in biology, it is one of the most problematic to teach and often leaves students with misconceptions they will carry throughout their adult lives. High school biology may be the last science course for some students, yet many go into the world without a clear understanding of this important topic (Lach and Loverude, 1998). By clearly centering units in a science course on ideas of change through time, attitudes regarding science as a collection of disjointed "facts" may be dispelled.

Many students fail to grasp the concept of how change occurs due to the topical approach most biology courses take in presenting information. Results of major studies such as NRC (1996), TIMSS (1996) , and AAAS (1990) concur that current curricula do not place enough emphasis on the key connecting concepts but focus on too many "unrelated ideas" (Nelson 1999). A biology course can place the focus on evolution throughout the year and build upon examples from each topic covered. The role of evolution as central theme is echoed in NRC (1996) and AAAS (1990) standards, and other research (e.g., Scharmann 1993, Zuzovsky 1994, Bull and Wichman 1998). Designing an entire year around change through time gives the opportunity to emphasize biology's most important theme and allows students to come away with a much more unified concept of biology, one driven by the principles of evolution.

Some challenges of this approach are the continuing social and legal controversy concerning the role of evolution in education. Despite the recognized importance of evolution, recent polls have shown that about half of all Americans do not believe evolutionary principles apply to humans (Moore 1998a, Alters, 1998). Why this continues to be the case 25 years after Dobzhansky's insights, and more than 100 years after the publication of *The Origin of Species* by Charles Darwin (1859) is disturbing to most scientists and science educators. Volumes have been written to lament the current state of evolutionary misconceptions and to suggest ways to correct this flaw in the educational system (See NRC 1998 for an excellent example); however, little research has been done within the science education community on the issue (Good 1994, Cummins and Demastes 1994, Rudolph and Stewart 1998).

Understanding evolutionary principles is one key to scientific literacy as well (Zuzovsky 1994). At a time when the impact of science on the public is greater than ever, the level of public ignorance is high (Aguillard 1999). Biology has advanced in unimaginable ways in the last decades and is even more vitally important as a field socially and economically. However, as Bull and Wichman (1998) point out, "... at a time when evolution is the unifying fabric of biology, it is barely mentioned in some high school textbooks and classrooms. Will the next generation of scientists be prepared to exploit these advances?"

If the stated goals of scientific literacy detailed in position statements such as Project 2061 (AAAS 1990) are to be met, clearly we must correct the misconceptions surrounding evolution. Proponents of creationism and the misinformation circulated by political groups are additional concerns that must be addressed in biology classes. The nature of science must be understood so that students are not swayed by emotional or religious sales pitches. They must understand the difference between science and pseudoscience. There is concern that the lack of general acceptance and understanding of evolutionary science will impact the public as they vote on environmental, health, and ethical issues (Eckstrand 1998, Bull and Wichman 1998, Drummond 1999). Also of concern is the background of future scientists who may not be trained in the fundamental principles of biology as they leave high school. Some of the difficulties arise as a result of social and legal opposition to the teaching of human evolution. The Scopes Trial in 1925 was a major cultural event in American history, spawning new legislation, legal and local school board battles into the 1980's, and even a Broadway play. However, there may be more to the problem of student mastery of the nature of evolution than of the social and religious views frequently expressed in the media. I believe that while the legal and social issues can lend an unhealthy environment to the biology classroom, and give reluctant students a potential way to avoid learning, a larger part of the problem lies in the topical approach and lack of time allocated to evolution in most high schools and textbooks used to cover the units in a typical course.

Evolution must be a recurrent theme in the biology classroom. Students must have time to ponder the evidence presented as they develop biological literacy throughout their course work:

> What key experiences lead students to make the shift from naive to Darwinian explanations of evolution remains as an unanswered question. [But] there is an indication that growth in understanding has a developmental essence, which in turn implies the importance of extended exposure to the key components of neo-Darwinian thought. [So] teachers are encouraged to persist in their efforts to teach the central ideas of the evolutionary process throughout the school year and not restrict their efforts to coincide with a predetermined block of time or a section from the textbook.
> (Settlage 1994)

As science teachers, we are constantly trying to help students observe and understand the world around them, to ask questions about what they see, to consider how it all fits together, and to actively seek solutions to questions through literature, discussion, and reasoned experience. Close observations and directed inquiry of natural systems will allow students to reach an understanding of the types and nature of changes in the natural world. They will come to understand that humans are a part of the natural world and are subject to the same laws of nature as are other organisms. Over time, such an attitudinal shift may help to change some of the public attitudes about environmental issues, as well as provide them the framework for comprehending health and medical developments. In short they must understand the role of evolution and humanity's place in the world to be intelligent citizens in the 21st century.

The Creation Science Debate

i. Background:

"In 1895 the Committee on Secondary School Studies of the National Education Committee (a.k.a. the Committee of Ten) recommended that evolution be taught in high school biology courses" (Grobman 1998). Darwinian evolution was recognized as a valuable part of the curriculum in the 19th century and continues to be the basis for national standards for biological education. However, there is a long history of legal battles regarding the teaching of evolution in this country. From Tennessee's Butler Law in 1923 to the current debate in Kansas, the topic of evolution continues to offer special challenges to educators.

The current state of evolutionary knowledge was used as a springboard for an eight month series of articles on "Creationism in the United States" by Randy Moore (1998a) in *The American Biology Teacher*. The topic of creationism is an interesting and worthwhile issue in and of itself, but Moore took the opportunity to review the legal and social history of the "debate" and to dispel some misconceptions that the public and many teachers have regarding how we have arrived at our present state of scientific knowledge. In the opening article Moore begins with a quick summary of the public opinion polls in the last 10 years to paint a picture of current cultural knowledge.

ii. The Scopes Trial:

The background of the Scopes Trial provided by Moore (1998a) showed the reality, which has been romanticized, the basic approach scientists take when challenged by non-scientists, the arguments used to convince the public of the merits of scientific ideas, and "...the importance of the creationism / evolution clash as a cultural struggle...." Many American's memories of the Scopes Trial are remnants of the fictitious 1955 play "Inherit the Wind" by Jerome Lawrence and Robert E. Lee, which does not purport to be historically accurate. Like Moore, I recalled watching "Inherit the Wind" in high school, although in sophomore English class rather than history or biology. Despite the disclaimers and screening in an English class, I, too, felt that the story was an accurate portrayal of the Scopes Trial at the time I saw the film. Despite my teacher's best efforts, I did not realize or understand the 1950's anti-intellectualism context either. Moore contends that the significant differences between trial and play have contributed to misconceptions of the trial and its outcome on the teaching of biology, but watching the film still a very valuable experience (Moore 1999b).

The trial had a profound impact on legislation and local action. In 1923-25 several states (California, North Carolina, Oklahoma, Arkansas, and Tennessee, among others, Moore 1998a) enacted legislation banning the teaching of evolution in the classroom. Many of these laws were not taken very seriously. Governor Austin Peay of Tennessee signed the Butler Law into effect with the understanding that "Nobody believes it is going to be an active statute" (Moore 1998a). However, the ACLU made the law a "manufactured test case" in the Scopes Trial and turned Dayton, Tennessee, into a central focus of world news in 1925. The trial originated as both a test case and a way to stimulate the local economy. No one had anticipated the scale of the trial and its worldwide attention or the "media circus" that attended it.

iii. After the Scopes Trial

Despite claims of victory on both sides, the legal battles continued as the Scopes decision was appealed and new laws were introduced. Several laws were passed outlawing the teaching of evolution, primarily human evolution. A crucial test of anti-evolution laws was Epperson v. Arkansas in 1967. Arkansas biology teacher Susan Epperson felt the need to include evolution as a basic principle of biology even though it was against the law in Arkansas at the time. She reported being torn between the need to be a good teacher and the desire to be a good citizen (Moore 1999a). Epperson's suit was filed and after a contentious trial the law was deemed unconstitutional. However, as Moore (1999e) noted, the power of school boards and other local groups to hire teachers and choose textbooks effectively prevents the teaching of evolution in some areas even today.

The last anti-evolution law on the books was in Mississippi which was not repealed until 1970, and then only in response to the Epperson decision (Moore 1998b). However, repeal of these laws opened the door to "Creation Science" bills attempting to treat creationism as a science. For example, Arkansas Act 590 was a so-called balanced treatment law calling for the same emphasis to be placed on creation science as on evolution in public schools. Act 590 linked creationism with biblical references, and was stuck down in 1981 by the McLean v. Arkansas Board of Education decision. At the time Act 590 was under fire in federal court, Senator Bill Keith introduced a balanced treatment bill in Louisiana that argued for the scientific merits of creation science without direct biblical references. This law also required the teaching of creation science if Darwinian evolution was covered. The ACLU challenged the law on behalf of 26 scientific organizations and individuals and Donald Aguillard was named nominal plaintiff. Aguillard was a biology teacher in Lafayette, LA, who refused to recognize the supposed scientific standing of creationism. The law was struck down in 1987 when the Supreme Court ruled it was advancing a religious doctrine and violated the First Amendment (Moore 1999).

iv. Recent Trends:

The lingering effect of creationism and the legal and social battles that have been fought in the name of evolution continue to haunt the nation's classrooms. The battle has been moved from the federal to state and local levels. As recently as 1987, more than one fourth of high school biology courses in Ohio included creationism and fifteen percent treated it favorably (Aguillard 1999). These rather shocking numbers from the science classrooms reveal at least one cause for the continued acceptance of creationism by the public; students are being taught that it has a place in a science curriculum. Some teachers allocated little or no time to evolution, which may be linked to their personal lack of acceptance of evolutionary theory. Reluctance also may be due, in part, to pressure from parents, administrators, or the public. Gould and Alters (1998) suggested that "the worst thing that happens is that creationists become effective because cowardly teachers under pressure just leave evolution out." However, the evidence suggests that biology teachers are less likely to be challenged over content material than teachers of other subjects (Patterson and Rossow 1999).

Creationism seems, if anything, to be gaining popularity (Moore 1999c). Teacher Al Frisby of Kansas City, Kansas, commented that about 40 percent of his students do not accept evolution, so he has managed to "agree to disagree" according to one parent (Christensen 1999). Frisby, like Epperson a generation ago, is most unhappy with this uneasy truce: " If there's no evolution I can't teach." Many people have trouble accepting the governance of the natural world by random chance or natural laws which are indifferent to human life. The nature of human evolution especially has been a point of contention and reflection since Darwin first wrestled with the concept in the 1800's. There is a need by high school teachers, and scientists in general, to demonstrate that evolution is not incompatible with religion, it is not an either/or question. As Kansas State University professor Lawrence Scharmann noted in the Salt Lake Tribune (1999): "[Students] don't have to *believe* (emphasis mine) these theories just know how to use them". "Evolution, like all good theories, is an excellent problem- solving tool (Salt Lake Tribune 1999)". Students must realize that science and religion are not set against one another but serve differing roles (Kiernan 1999a). It is important not to polarize students by trying to change the beliefs they value from their parents (Salt Lake Tribune 1999). Belief systems accepted on faith play a role in personal development but have no place in the scientific debate except as examples what is scientific and what is not (Smith and Scharmann 1999).

Current regulations such as the labeling of textbook's disclaimers (in such states as Texas and Arkansas: "Evolution is a controversial theory...") clearly attempt to undermine the teaching of biology as a conceptual whole (Christensen 1998). In 1990 and 1994, legal cases were heard where teachers attempted to include creation science in the classroom. In both cases, the decision cited Edwards v. Aguillard and stated that creation science is a religious and not scientific principle. The courts ruled that religious doctrine had no place in a public school curriculum (www.natcensci.org 1999). The current debate in Kansas regarding the adoption of state-wide school standards has again brought the controversy to the public's attention. The Kansas Board of Education split (5-5) on a vote to adopt the standards, which were written by science teachers and based on current nationally recommended standards. Conservative board member Steve Abrams rewrote the science standards removing all but one reference to evolution and adding a definition of creation referring to creation by a supreme being (story reported in the Salt Lake Tribune May 22, 1999). On August 11,1999 the Kansas Board of Education voted to accept the version of the science standards rewritten by Abrams (New York Times 1999).

Other factors that may contribute to the public's perception of evolution concern their lack of understanding of the nature of science. The poor rhetorical skill of some scientists and the common use of scientific terminology such as "theory" and "fact" serve to confuse the public and seemingly separate scientists from the general public. The vitality of scientific debates concerning the mechanisms of evolution also led to a misconception of scientists' uncertainty in the minds of the public. The demand that Darwin or current biologists demonstrate evolutionary transformation are unrealistic and unwarranted (Rudolph and Stewart 1998). These issues may be best resolved through increasing care and depth of education. However, a continuing apathetic American attitude toward education in general also may be a factor. Biologist S.J. Gould suggests that if we ask similar questions from other fields or disciplines the response of the general public would be similar, with about 50 percent expressing little or no understanding of physics or historical concepts (Alters 1999).

Textbooks, teachers, school boards, and even state legislatures continue to assault the teaching of the unifying principle of biology. If nothing makes sense without an understanding of evolution, then how can we attempt to teach biology without giving students a fair opportunity to understand the principle? I suggest that evolution is not a unit or topic within the course "Biology", but the core component that is the basis for every activity. A strategy is to begin with the familiar and add a deeper understanding of the structure, function, and interactions of organisms as the student becomes more aware of the natural world. "Natural selection should be offered as an explanation for familiar phenomenon and then revisited as new phenomena are explored" (AAAS, 1993). It is important to deal with the specifics of each topic, but it is more important to give each student an understanding that evolution is not a piece of biology but an underlying theme in every area. Hence, "... the authors of *Science for All Americans* (AAAS 1990),*make evolution of life* a central theme in the life sciences, and *evolution* one of the six common themes across all the sciences (Systems, Models, Constancy, Patterns of Change, Evolution, and Scale) " (Good, 1994). From a familiar walk around the campus to look for evidence of biotic and abiotic interactions, to the specific examination of leaf cell structure to determine the location of chloroplasts for a cell model, evolutionary principles help explain what is being seen and why organisms function as they do.

Teacher Reluctance to "TEACH" Evolution

"Many biology teachers avoid teaching about evolution or present it poorly." (Moore, 1998a). For example, surveys by Zimmerman in Ohio and Tatina in South Dakota showed that 38 percent and 39 percent, respectively, of high school biology teachers think creationism should be taught in public schools (Aguillard 1999). The research concluded that "Considering Evolution's importance as a unifying concept in biology..." evolution was not being emphasized to a degree commensurate with its status in at least 50 percent of the Biology 1 classes (Aguillard 1999). While legislatures continue to argue the role of governmental control in education, many students are not getting a background in one of the six common themes in the sciences (Good 1994).

Aguillard (1999) found that the level of education attained by the teacher played a significant role in the amount of time spent by the teacher on evolution. One quarter of teachers in that study felt that their background was inadequate to teach evolution, and only 13 percent gave students more information than was in their textbook while about 50 percent presented less than what was given in the text. This was especially disheartening in light of state guidelines mandating disclaimers, local adoption of texts that downplay evolution, and demands for balanced treatment of non-scientific doctrines such as creationism. At a time when the amount of information teachers and students are confronted with can be overwhelming the time spent on creationism in a balanced treatment situation may sway teachers to avoid the topic of evolution entirely in the interest of time. Indeed, 42 percent of the Louisiana teachers felt they did not allocate enough time to evolution currently.

Personal beliefs of teachers also may have an impact on the coverage of biology. For example, 24 percent of the respondents in Louisiana believed that creationism had a scientific foundation, and a strong correlation was found between time allotted to the teaching of creationist topics and belief in its scientific validity (Aguillard 1999). Ironically many teachers were prepared to not cover evolution at all rather than devote time to creationism (Moore 1999c).

Despite the recommendations in the national standards, there appears to be no pressure to regard evolutionary theory as a unifying theme in biology instruction (Aguillard 1999). Administrators and local school boards must provide the support for teachers to upgrade evolutionary content and methodology in the classroom. "Many biology teachers don't mention evolution out of a fear of reprisal" (Moore 1999c). The concern that students, special interest groups, parents, or school boards may object to the teaching of evolution also may be a factor in the small amount of emphasis given to evolutionary theory. Gould has been quoted as saying that "I think it's important that biology educators not soft pedal evolution or teach it as a small and peripheral voluntary subsidiary topic at the end of a long course. I think one needs to teach it on day one and point out that it's the central concept and unifying notion of the biological sciences" (Alters 1998). These problems are not well addressed with the standardized tests either. In some states, the call for state standards testing has been counterproductive; Louisiana's state exit exam for high school does not include evolutionary topics (Moore 1999f).

Teachers have a variety of reasons for not putting more emphasis on evolution in their classrooms, including time constraints, lack of confidence in their backgrounds, fear of controversy, lack of administrative support, and personal belief systems. If the nation cannot reach a public consensus on the value of evolution to the teaching of biology from the public to match the commitment expressed by scientists, many teachers will not give evolution a central place in biology education. The continuing publicity concerning creationism allows one special interest group to prevent many teachers from emphasizing evolution to the extent intended by the standards. Perhaps, Good (1994) best summed up the debate by stating: "Evolution education should be as important to science (biology) education as evolution is to biology."

Importance of Evolution as Central Theme to Meet Standards

One of the stated goals of *Science for All Americans* is the development of scientifically literate citizens. High school teachers also have responsibility for helping to create good citizens. "Our educational practice should keep clearly in mind that in the introductory science classroom our primary goal is to produce effective citizens, not scientists" (Smith and Scharmann, 1999). So, one of the problems that the framers of national and state standards have encountered is the lack of control over classroom presentation. All teachers have their own styles, strengths and weaknesses, as well as topics they prefer to emphasize. The standards are designed to ensure that all students receive similar educational background prior to graduation.

The framers of the national standards are in agreement that evolution is the central theme in biology and one of the unifying themes across all sciences (AAAS 1993, NRC 1996). The standards are clear; teachers must make the commitment to follow the recommendations for their students to achieve scientific literacy. The concept of evolution must be used throughout courses to reinforce the commonalties of all forms of life. Students learn in incremental steps, each step must be laid upon a solid foundation of preceding steps and the steps must be continually constructed, reinforced and directed to lead to the next level of understanding (Pearsall, Skinner, and Mintzes 1997).

Aside from the content aspect, evolution also is a tool that enables scientists and students to understand and explain their observations of the natural world. The theory provides a unique framework to make biology curricula a coherent whole rather than bits and pieces of information concerning seemingly unrelated topics. Without a solid framework, students often leave biology classrooms with little comprehension of the interconnectedness of organisms or the similarities in the processes that are used to maintain life. The use of evolution as a central theme makes biology a unified quest for discovering patterns in organization and function of the seemingly infinite variety of living things.

Covering evolution also creates unique opportunities to fully explain the impact biology has on other disciplines. History is not complete without a discussion of the influence of scientific exploration and the discoveries that helped lead to the formation of Darwin's theory. For example, "Many scientists and historians consider *The Origin of Species* (1859) by Charles Darwin to be the single most influential scientific book ever published" (Good 1994). A treatment of the history of the influences on Darwin as he prepared to publish can illustrate that science does not operate in a vacuum: it is not all lab coats and sterile equipment. The historical background also can be used to show that our knowledge has not stood still since Darwin's time. A discussion of recent advances in our understanding of mechanisms for evolution gives students a realistic picture of the nature of science. Theories can be modified without being discarded, and building upon the ideas of others is one method used to further understanding of the natural world.

A further feature of the use of the history of evolutionary theory is to show the importance of debate to the sciences (AAAS 1993, Alters 1998b) . Controversy is a part of the process of constructing a workable and defensible theory. Other scientists must be convinced of the merits of changing a consensually held idea. Defending ideas in a forum of one's peers will point out areas of further research or perhaps angles of attacking a problem not previously considered. Students should be encouraged to understand the importance of debate and peer review to the development of ideas.

Curriculum Shift From Textbook Dependence

Much has been written about the state of American textbooks. Nelson (1999) went so far as to say they may impede learning with their emphasis on learning answers versus exploring new questions, memorizing bits and pieces of information versus learning in context. There is also the question of textbook accuracy and publishers motive. As shown in Moore (1998b), publishers are quick to respond to public opinion. Even though both sides claimed victory in the Scopes Trial, the word "evolution" virtually vanished from the nation's biology texts in the next couple years. The responsibility for improvements in these areas may fall to teachers of the biological sciences. Teachers are most familiar with the textual material, the content needs of the students, and are in a position to influence administrators and school boards with firm insistence on the importance of evolutionary theory. There are extensive summaries of textbooks in science journals (e.g. Germann, Haskins, and Auls 1996, Jimenez Aleixandre 1994) that are easily accessible and could be used to help convince reluctant officials of the central role evolution plays in "better" textbooks.

The Nature of Science

The "nature of-science" has become a topic of much discussion in recent years and has been described as "...an active process of making sense of the natural world..." (Rudolph and Stewart 1998). Some of the conceptual difficulties students have in understanding the concept of evolution by natural selection may come from confusion regarding the historical or descriptive sciences as opposed to the more traditional cause and effect model of science based upon physics. Some of these problems may be caused by trying to force evolutionary theory into a model of science that is based upon the establishment of universal laws which lend themselves to experimental confirmation rather than descriptive or historical models. It has been suggested that this concept of science as a collection of universal laws is a significant stumbling block to understanding evolutionary biology and ecology. These topics deal "...with multiple interactions among highly complex systems that are susceptible to easy disruption by study" (Rudolph and Stewart 1998) and often deal with evidence gathered over extended periods of time that may be difficult to reproduce in the classroom . The notion that all science is experimental and that theory supported by observation and historical discovery is less rigorous science and somehow suspect does not fit the biological model. Rudolph and Stewart (1998) suggest we focus on the use of science as constructing not just "models" to explain what we can test but models to provide both explanation and a basis for the ongoing inquiry that is the heart of science. "What students encounter in the classroom is often presented as a kind of final-form knowledge - a 'rhetoric of conclusions'...." We tend to portray science as a static body of knowledge even if we acknowledge that ideas change with new evidence. The depth to which evolution enables one to understand all of biology cannot be seen by doing an "experiment"; one must emphasize the nature of science as an investigative and descriptive process.

CHAPTER 2

INTEGRATING EVOLUTION INTO A YEAR-LONG BIOLOGY COURSE: A CASE STUDY AT ST. JOHNSBURY ACADEMY

Every aspect of a life science course can be tied directly to the concept of change though time by carefully selecting instructional activities in a year-long curriculum. In a pilot study year, I crafted units to focus on the concept of evolution by natural selection and I looked for opportunities to reinforce this central theme. Introductory courses obviously lend themselves to this approach because evolution is the common thread in all biology and a survey is greatly enhanced by the use of a central, reoccurring concept. Focusing on the issue of common descent allows complex topics such as photosynthetic and respiration pathways to be related and understood in context. The students learn to look for similar compounds used in both processes and the central role these molecules have in the conversion of energy. The same focus on similarities between organisms helps students to come to their own understanding of the role common descent has had on the diversity of living organisms.

Description of the School

i. The Academy

St. Johnsbury Academy is a medium-sized (about 900 students-see Table 2.1), 9-12 grade high school in northern Vermont. This private school is actually a large school by Vermont standards. The school is private but accepts the majority of its students from the town of St. Johnsbury and surrounding smaller towns that do not have a designated high school, basically on a voucher system. Students from these towns are free to attend other schools if they wish and tuition is paid by the towns. Children from the majority of these neighboring towns attend "The Academy" and slightly less than half the student population comes from St. Johnsbury itself. In addition, the school runs a boarding program with about 150 students from such places as Korea, Bermuda, Japan, Saudi Arabia, Germany, and Brazil as well as the United States (See Table 2.2). This creates a rather unique educational opportunity for students from northern Vermont. Classes meet daily Monday through Friday and are 41 minutes long. There is no extra lab period for science classes. All science classes are taught in a modern (opened 1994) combination lab/ classroom setting. There are plans to begin an eighty minute period block schedule format in the 2000-2001 school year.

ii. The Area

St. Johnsbury, Vermont, is located in the temperate deciduous forest and experiences a seasonal climate. St. Johnsbury is a small town (less than 8000 people) in a rural area with a farming history. The fall foliage makes the change of seasons a dramatic event. The region has not experienced any recent controversy over the teaching of evolution, and outside of a few students from deeply religious families, the merit of evolutionary theory is not at question. As Stephen Jay Gould pointed out "we are not used to running into creationists in New England" (Alters 1998). Even the more religious students have, in my experience, been open to discussions of the theory of evolution and have responded favorably to discussions on the historical background of evolutionary theory. However, as Alters (1999) points out there is much room to improve understanding of evolution in all schools.

iii. The Biology Course

Biology is taught as a Freshman level class and, as such, is the first science learning experience the students have in high school. As a department we have put many hours into aligning our current programs with the recent standards-based approach. Vermont, like most other states, has published standards that are closely allied with the national recommendations (AAAS 1990 and 1993, NRC 1996). These standards uniformly stress the importance of evolution as the recurring theme in all of biology. After much discussion and yearly reviews of content and methodology, the faculty in our science department have arrived at the following schedule of content areas to be included in the biology curriculum. We began the year by discussing the nature of science with specific examples from the field of biology. Following that introduction, we emphasized ecology to end the first quarter (seven weeks). There are many reasons for the "out of order" sequence (compared to most textbooks): some of the topics of the ecology unit are well known to the students such as global warming and ozone depletion, the introductory material is mostly macroscopic, and most importantly for northern Vermont, it allows us the opportunity to use directed observations of the natural setting- we can go outside without freezing! This timing also gave the students an opportunity to begin a fall project after they had a basic understanding of ecological topics. The third unit focused on the role of energy and the systems that have evolved to deal with energy conversions in living organisms. Cell biology was taken up next, with an emphasis on the similarities of cell structures and organelle function. A study of DNA and protein synthesis led to Mendelian genetics and then the historical background to evolutionary theory. A sixth unit was a survey of the kingdoms and organismal biology including human's place in the natural world. I departed from my colleagues the last two weeks of the school year and studied botany and plant ecology to finish the second semester. At this point the students had a more complete understanding of organisms in the local ecosystems and why ecosystems are structured as they are. A return to ecological principles at this point allowed me to tie the year together with a direct link back to the beginning of the school year.

The text used at St. Johnsbury Academy is Prentice-Hall's *Biology* by Miller and Levine (1991). It is was used not as a primary direction for the course but as a common resource for all the students. The text often was used as a source for homework responses but usually not as the source for the questions. Typically the class period ended on the verge of the next step in a process of discovery, and as such, the homework questions came from the discussion or activity, not from the questions on the next page or at the end of the next section of a text. Often the questions for homework came from the students themselves during the course of their learning.

While this open style made keeping to a strict syllabus nearly impossible, it allowed the use of a flexible "syllabus" outline that does give the framework of the unit and an outline of each lesson's objectives. Some of the students complained at the beginning of the course that they could not work ahead or know exactly what will happen in class beforehand, but as the first few weeks progressed these students began to see how the course flowed, and they often researched far beyond the text in search of solutions or questions on the unit. This strategy also allowed students to feel comfortable incorporating their prior knowledge into the discussion and allowed the teacher to look at their background knowledge and misconceptions rather than merely wading through pages of responses taken from the text. By the same token students began to expect that the class would be working on *their* questions not the text's questions.

iv. The Students

At St. Johnsbury Academy, students are initially divided by achievement on an entrance exam with the top 20 percent invited into accelerated classes. Most all of the students tested were freshmen (with the occasional exception of foreign students). Their progress is closely monitored for the first semester and shifts in levels are arranged accordingly. The accelerated level is intended for students looking to attend highly competitive colleges, and they are likely to be interested in the sciences. These students have proved to be highly motivated as well as high achievers. Several of the students selected for the accelerated level will not meet the standards set for them and will be moved to a level where they may be more successful. Many of the students who stay in the accelerated level will be enrolling in Advanced Placement sciences as juniors or seniors. At the accelerated level, the students have a strong academic background and most can learn not to accept statements at face value without supporting evidence. A goal is to teach students to be skeptical of the text and teacher and to utilize their own background and senses to "test" statements and hypotheses. During the pilot study year, the students in my two classes were all freshmen except three (a junior German residential student, a sophomore transfer student from a local school, and a sophomore residential student). Most students were day students from the St. Johnsbury area and ten of them had parents who were educators (elementary through college) or physicians. All students in my classes were required to complete a research paper each semester (ecology theme in the fall and genetics theme in the spring). These were carried out by the students outside of class; the goals were to encourage students to find solutions to questions brought up in class, to help students gain a grasp of the research process, build confidence, and to give requisite experience for a "capstone" project to be completed late in the junior year after three years of science. Most accelerated students have continued on in the sciences throughout their high school career with at least four science courses; many pursued science in college.

v. Assessment at St. Johnsbury Academy

The grading format used in my classes began with a school-wide policy to assess each student 20 percent (or more if applicable- foreign languages assess 50 percent) for daily performance. This encompassed tardiness, unexcused absences or failure to makeup absences, preparation for class such as completion of homework and bringing needed supplies, attention and participation in class discussion and activities. Five percent of the student's grade was assessed from homework randomly collected three to six times per quarter. Another five percent was based on unannounced quizzes used for test preparation (these could be retaken if desired). The function of the quizzes was to help students prepare for tests and to allow assessment of student understanding. In the second and fourth quarters 20 percent of the grade came from projects such as research papers and book discussions. Another 20-30 percent came from two or three unit tests each quarter, and the remaining 30-40 percent of the students grade was assessed from their lab journal. Each activity in the journal was graded, and the overall completeness of the journal was assessed at the end of each quarter. The range of weights allowed flexibility for grading of the project during the second half of each semester.

Using an Evolutionary Theme Throughout the School Year

The project assignment evolved over the past four years from a dissatisfaction with a traditional topic-based biology curriculum. The biology curriculum at the Academy had been a very traditional text-driven treatment course with a syllabus that attempted to cover the entire 1000+ page text in the school year. Little time was allotted to group or inquiry lessons, and lecture was the predominant method of instruction. Not only was the format restrictive and stifling, the schedule was impractical and teachers inevitably fell far behind and felt frustrated that all the topics were not covered. This dissatisfaction has facilitated a switch to a curriculum that seems to follow the logic of the student's inquiry process. We also can make use of the opportunities to spend time outside in a natural setting that we are afforded in rural Vermont. By focusing on a year-long theme that is consistently revisited and elaborated upon, the students get the sense that biology is a coherent study and not merely a set of disjointed topics (with a corresponding set of "facts") to be memorized and forgotten after the unit exam. While the initial activities have not changed appreciably their focus has been sharpened and every opportunity is taken to reinforce how the current topic fits within the evolutionary context of biology.

General Types of Classroom Activities

i. "Group Work and Discussion"

In all class activities, collaboration was encouraged. The students quickly became accustomed to a discussion format where they were free to ask questions, relate experiences, or interject opinions. For lab activities, groups were reassigned until everyone had worked together. This process took us into the third quarter. After everyone had worked together once, students were allowed to pick a partner based on prior collaborations and the labs became joint efforts. Grading consisted of quizzes, exams, projects and a lab journal.

ii. Open-ended Inquiries

In all the activities described below, much of the planning and organizational work was left to the students. This open-ended approach helped to prepare them for the long term projects that they did each semester and helped to eliminate the "cookbook lab" syndrome as much as possible. While we worked within certain time, material, and specific content constraints, I tried to free the students to make as many decisions as possible. The questions that we tried to answer were interpretational, challenging, and open-ended, often requiring resources other than the text. These types of questions were important components of group activities as well. Example activities and assessments are shown in Appendix I.

iii. The Lab Journal

The lab journal was the center piece of the course. This was reflected in the grading weight and in the time (two to three days per week) allotted to "lab" activities. We began the year with a reading from *Zen and the Art of Motorcycle Maintenance* (Pirsig 1976) stressing the importance of the thought process involved in attacking a problem using the scientific method. This emphasis on the mental aspect of the scientific method helped students get over the "cookbook" (just -follow -instructions -without- really -thinking) approach to labs. In their lab journals, students started with a blank sheet on which they formulated ideas and took research notes. The format forced the group to listen to the problem and find ways to resolve the problem without relying on a list of procedures. A hard-bound composition book was the appropriate size (100 pages) for most of the students and was distinct from the rest of their notebooks in their lockers or backpacks. Removing pages was discouraged by a 10 percent penalty on their lab grade. These journals served the students as a sort of portfolio of their work; they saw what they had done in class as reflected in lab and could evaluate how much they had progressed over the course of the year.

Moreover, it served as a vital written record of the observations they had made and allowed quick reference to activities that dovetailed to show organismal adaptations to our area. The lab journal also provided the student with a framework of the course to illustrate the thematic approach.

Ways to Tie the Year Together Using Evolution

i. Long-term Projects

The use of long term projects and writing as a technique to increase inquiry and student organization has been underutilized (Havel 1995) in high school classes. These projects increase skills in writing and research, focus students on large scale concepts, and make them see detailed changes in populations and ecosystems in biology.

Several long term projects were utilized throughout the year to encourage students to see the ways in which the topic areas fit into the larger scheme of biology. These projects also encouraged students to discover "the nature of science" in a real, hands-on manner. The fall semester project was based on ecology and was initially brought up in the second class period of the year as we discussed grading procedures. Students were then prepared, and often reminded, to watch for questions of interest both in class discussion and as we looked at the local environment.

In the second semester the student projects focused on genetics and inheritance of adaptive features. In class we did a Mendelian genetics project using *Drosophila melanogaster* (homozygous strains are easily available through science catalogs such as Carolina Biological Supply). We followed the results of two factor crosses to the F_2 generation. While this activity is fairly common in biology classes, some students then chose to do further research using the fruit flies for their second semester projects. Four students looked at mutation rates in the subsequent generations and one group designed a box to test if the flies are more likely to turn right or left and if this trait is inheritable. Several others constructed family pedigrees and some even followed traits in their purebred pets.

ii. Book discussions

Popular books written by scientists were used as an invaluable tool to get students to see the work and thought process of scientists. Table 2.3 gives a list of some books that the students used. These books provided background information and a more detailed look at a topic that was only surveyed in class. The assignment consisted of reading the book and in-class discussions of the author's background (for credibility -who is the author and why should we believe them), the copyright date (for perspective), the author's argument (why did they write the book, what view are they trying to persuade us to take), the evidence presented to convince the reader, and the student's opinion. In the future we will take a chronological approach according to the first copyright date to better show the developments and modifications within biology over time.

Examples of Guided Inquiries Related to Evolution

Example 1. Leaf measurement- Genetic variability

One of the first investigations that we did addressed information that would be utilized later in the ecology, cell, genetics, evolution, and botany units. This investigation was designed to illustrate one of the basic principles of Darwinian evolution; that individuals within populations and species exhibit variation in structure. Variation with a population provides the differences between individuals that natural selection works upon. We were able to see the variation in leaf size from tree to tree and potential advantages in different habitats.

This investigation extended over three class periods. Not only did students get practice in the proper use of measurement tools and recording data in table and graphic form, they also learned how to develop a lab write-up in the format that was utilized throughout the year and practiced working with partners (and getting to know each other).

The essential question in this investigation was "how big is a leaf" which led the students to realize a great deal of information was needed to answer the question. The question was purposefully very vague and required the class to wrestle with how to focus such topics to a manageable and, therefore, testable size. First, we decided as a class which type of leaf to work with (being from Vermont we chose sugar maple). Next the students decided what the general term "big" meant; while that decision was left to individual groups most chose length and width as ample measures. Students were asked to gather ten leaves as a homework assignment. This gave them the opportunity to discuss with their partners and within the class the several *Acer* species in the area and learn a little about closely related species because several students brought in leaves of both red and sugar maples.

The students noted where the leaves came from on the tree as well as any environmental factors they considered important. The following day, students measured length and width of their leaves and data were shared between classes. Other interesting observations were noted (e.g., leaves from shady areas are often larger). Some students decided to measure surface area and got the opportunity to devise a method for an irregularly shaped object. Students found the mass of each leaf using an electronic balance. The leaves were placed in a drying oven until the next day when they were reweighed so the percent water in the leaf could be calculated (see Activity 1). As students developed measurement and data collection skills, they also learned about environmental and habitat conditions. Their leaf and environmental data introduced them to genetic variability within and between species.

The inquiry required no more set up time than a "cookbook" lab on methods of measuring in science using common laboratory items but provided a wealth of data which was called upon in later lessons and allowed lots of student input into the methodology (how and which data they collect), how to best represent the data and that there are no "wrong" answers to such general questions.

Students used this inquiry to learn to begin a search for topics for later papers, use common lab instruments, collect and report data, and draw conclusions based upon the data gathered. The students were assessed according to their participation, as well as the analysis presented in their lab journal. They came away from this investigation with an better understanding that general ideas can be focused into specific questions using a scientific approach. They had a better understanding of how questions can have many answers depending upon the methods, and that the reporting of these methods was as important to the solutions as the data they analyzed. The students learned that science is an ongoing process and that data are open to discussion and interpretation based on methodology. The concept of genetic variability introduced here was elaborated throughout the year as the raw material upon which natural selection and organismal evolution works.

Example 2. Predator -Prey Adaptations

Predator-prey interactions are an important component of an ecosystem, and a wide variety of activities exist to show how populations of one species can effect change in another species. Adaptations such as defense mechanisms offer an excellent opportunity to illustrate adaptive features and how selective pressure can eliminate disadvantageous phenotypes from a population. This conceptual understanding of how populations change is important underpinning for the understanding of evolution and the possibility of extinction (Brewer and Zabinski 1999). This predator-prey inquiry allowed students to work outside, make observations of their natural surroundings, and gain understanding of how populations change in response to selective pressures.

This inquiry is a modification of the fairly common predator / prey activities described in many lab manuals. A variety of beans comprised of red kidney beans, lima beans, and whole green peas were used as "prey". A 400 mL beaker of each type of bean was taken to a field hockey field (the lawn mower and lateness in the growing season prevented any rebuff from angry maintenance men or coaches). Three students were chosen to quickly disperse the prey within the field perimeter while the other students assembled themselves in the bleachers. When the beans were dispersed students had three 2-minute periods to gather as many beans as possible. At the end of each two minute period they were given two minutes to return quickly to the bleachers, record the time period, count the number of each type of bean they had gathered, and replace the beans in the appropriate beakers. As predators the students were not allowed to run without penalty of increased energy use of five beans. This rule continued an ongoing theme of efficiency in energy use as crucial for survival.

The number of each type of prey gathered was noted and students organized their data to search for patterns in the results. Students compared number and volume of each type of "prey" caught. They found nearly all (400 mL) of the large, white lima beans, about two-thirds of the red kidney beans and less than half of the green peas. The number of each type of prey collected led to discussion of the size difference and differences in original population size. Issues such as size and protective coloration were discussed. Students were amazed that the red kidney beans were so difficult to find among the mixed green and brown colors of the lawn. Students also dealt with some sampling problems. For example, some groups did not finish sorting and counting after two minutes, so they had less time to forage when the next collecting period began. This illustrated the varying degrees of assimilation efficiency of individuals within a species. The grouping of prey populations within the field was discussed because the dispersers were not expected nor able to distribute the prey evenly. The possibility of extinction was also brought up concerning the lima bean population and the small likelihood of ever capturing all the green peas (at least prior to germination!). We also considered the implications of the data from two different perspectives: a) assuming the three types of beans were members of distinct species, and b) assuming the three types were variants within a single population.

The value of this type of outside inquiry are several. First is the great detail with which students came to see common everyday sights . For example very few students realized that there are a lot of brown, decomposing, leaves even in a green lawn. Second, the energy with which they searched was well worth the effort. This was due to the interest brought to a clearly defined outdoor inquiry without the structure of the four walls around them. Third, the inquiry led to a discussion of prey defense mechanisms, adaptations of both prey and predators (students can use different utensils to gather the prey), the difference individual variation makes in their potential for survival as well as for the population, and the notion that "survival of the fittest" in this environment does not necessarily convey a "better" individual, only one more likely to survive in these conditions (for example, would the same pattern be observed in January if the environment changed).

Example 3. Natural Observations and Succession

Observations in nature were used early in the year to illustrate topics in ecology. These included simple guided walks around campus and more focused activities relying on detailed exploration of stages of succession in the northern temperate deciduous forest, including species diversity and community structure. The inquiries on population dynamics during the school year focused students on careful observation and provided background for discussions of population and community change through time, as well as a clearer understanding of variation within individual species.

On a guided walk, interactions between organisms as well as between organisms and their environment were easy to point out. Surprisingly, few students had ever noticed the variety right in front of them every day. There are many explanations for the failure to truly see that which is most common (Wandersee and Schussler 1999). Guided observations allowed students to develop a new appreciation for the small daily activities going on in the natural world around them. Seeing the interaction of squirrels and trees, not to mention powerlines, was much better than listening to a lecture on mutualism and symbiosis. Observation sessions gave students a chance to examine the interactions of biotic and abiotic elements, as well as human impacts in developed or disturbed areas in contrast with relatively undisturbed climax areas. These guided observations fueled later discussions on the adaptations that organisms have evolved over time that make them suited to live in deciduous forests. Walking around and making observations also developed a common background for students so those not lucky enough to have traveled much or have parents who point out such things were able to contribute later when we discussed, for example, genetics or Malthus' influence on Darwin. Assessment was based on the extent of student field notes on the organisms and interactions that they observed. The guided walks also developed a common experience for them to apply as they begin to formulate their own questions regarding the structure of the natural world. Students also found these tours to be invaluable as they searched for research topics that were manageable and meaningful.

Example 4. Public Perceptions of Northern Forests:

During a unit on public perceptions of our local forests, humanity as part of nature and, ultimately, dependent upon nature was stressed. Humans also cause changes. This inquiry focused on gathering information on human interactions in forests of the northeastern United States. Students were asked to clarify quality of life issues and reach consensus on controversial issues (e.g., paper use). After a brief lecture on the boundaries of the Northern Forest, pamphlets on the philosophy of the Northern Forest Alliance group were distributed. On their own, students were asked to find articles on hunting regulations, logging practices, land ownership by a paper company and the government, as well as on development within the area. Public versus private land ownership was frequently in the news. Because the East does not have a history of public land ownership, local groups are very suspicious of government intervention. Student groups prepared and introduced a bill to the "legislature" of their classmates on an issue that arose from their research. Their position was not critical since all "sides" were addressed; thus, groups did not fall prey to opponent claims they were uninformed. As each group made its presentation, classmates took notes on the information provided and were given the opportunity to question the bill's sponsors. They recorded the information they heard both for and against the bill and then voted on the issue. The ballots listed each student's perceptions of the pros and cons; these were collected and tabulated. Students were graded on participation, presentation, and the sophistication of analysis recorded on their ballots.

This was a fun and informative way to tie together student understanding on temperate forests, and to consider how human decisions affect the natural world. Students were able to incorporate information on how regulations affect organisms in the Northern Forest ecosystem. Population dynamics were addressed, both from the standpoint of human growth and impact and the increasing habituation of deer and moose (recently returned in large numbers to our area) to humans and the problems caused by the demands for space. Moreover, this approach related well to Vermont's tradition of the town meeting in which their parents participate and gave a clear view of how human decisions impact organisms and cause population change though time. A study of human influences on the population dynamics of deer and other game species showed how human activity is often counter to natural systems, for example, by harvesting the largest prey and leading to "survival of the smallest." Students were made aware of the role of the human animal as predator and as environmental manipulator in the evolution of other species.

Example 5. History of Evolutionary Theory:

a. Background Lectures and Readings:

Near the end of the third quarter, after students had developed a base of common experiences from class activities, we discussed the history of evolutionary theory. This began with a dialogue on the myths and religious explanations for the types and diversity of organisms in the world today. Topics considered included student experiences, how explanations have changed as scientific understanding has advanced, how we know what we know, and what differentiates good science from myth or religion. These systems of understanding were not judged but discussed in terms of their role in human understanding. Clearly viewpoints and our understanding of the world is quite different than that of pre-1800s scientists and travelers from long ago. The changing world was discussed as it related to scientists' understanding of the world, a world which was rapidly expanding in the late 1800s. Student notions of history contributed to the class background so a common foundation was developed. Eventually, students were focused on developments in science and asked to confront issues as scientist would: by looking at key questions, examining alternative explanations, weighing evidence and choosing the best explanation for new information (Lawson and Platt 1999).

The influence of leading scientists and public figures as well as other evidence was discussed as they related to the publication of Darwin's *The Origin of Species* (See Table 2.4). Science was discussed as a process and sometimes, competing or contentious ideas. Students developed understanding of the value of each contribution even if the ideas offered were no longer accepted today. Student readings in their text and from S.J. Gould articles provided the required background details (e.g. Gould 1980, 1981, 1991, 1993, 1995). Darwin, as theologist, scientist, person, and writer also was introduced to show the human side of science. Understanding Darwin's voyage on the H.M.S. *Beagle* offered insight into the value of close observation and background evidence for natural selection. As students developed a picture of the changing concept of how life has evolved and related this to what they have seen locally and in media or from traveling, they were encouraged to weigh the evidence and discuss their understanding from a scientific light. Geological, biochemical, structural, biodiversity, and population evidence of change through time was discussed.

As the students gained an understanding and appreciation for the way in which a theory gains scientific validity as well as the historical significance of Darwin's ideas, current ideas of how evolution occurs were introduced and the distinction between the theory of evolutionary change and the possible mechanisms by which the changes occur was clarified.

The culmination of this unit on the history of evolutionary theory was role playing using key figures from the history of the development of evolutionary theory (see Activity 2). Students picked a role- some roles called for more than one student- and prepared to discuss or defend the ideas of their "character" in a public forum. The students spent time out of class preparing for their role. Most of the research they did came from Gould's articles collected in books such as *The Panda's Thumb* (1980), *The Flamingo's Smile* (1981), *Bully for Brontosaurus* (1991), *and Dinosaur in a Haystack* (1995). The characters chosen represented not only important contributors but also figures for whom significant background information was available in the writings of S.J. Gould. During the time the students prepared for their role playing, mechanisms for how change occurs in nature were discussed in class. The forum was held in special 80 minute block. Students had 10 minutes for last minute preparations. Without prompting, over half of the students came dressed in period clothing to get into character better. The majority brought props to help explain their ideas. The instructor's role introduced each "guest" formally, which put a serious tone to the proceedings, maintained order, and made sure each student had the opportunity to contribute. Moreover, the instructor clearly noted participation and faithful adherence to the ideas of the character.

The final ten minutes of class were used to discuss any misconceptions presented and to debrief the activity. Students were graded on their contribution to discussion and the accuracy with which they portrayed their characters. The forum was occasionally heated, as in the real world, but it never lacked civility, and was great fun for all students. One of the difficulties, as in any such forum, was to make sure all students had the opportunity to have their say. Several students said they had much more to contribute but did not have the time. Many remarked how much they liked role playing and even the quieter students enjoyed the show and participated fully, if not with the same flair as their more vocal peers.

Example 6. Botany with a Return to Ecology

To bring closure to the school year theme of evolutionary change, students completed a short unit on botany with combination of inquiry-based and outdoor observations of plants (see Activity 3). The natural wonder of spring is often lost on students as they rush through end of school year activities (Wivagg 1991). Moreover, the lack of botanical coverage in introductory biology courses has often been noted (Hershey 1994, Wandersee and Schlusser 1999). Plants can be used to illustrate the adaptive features of evolutionary history as well as provide many examples of common descent. Using nature as a laboratory also facilitated review of the ecological principles discussed in the fall. This unit was the climax of the entire course and was used to tie everything together.

The inquiries made during this unit included both lab-based and outdoor experiences. In class, we looked at the structure and function of plants, emphasizing common cell types and roles in energy production, storage, and transport, as well as the basic tissue types used to organize plants structurally. Outside plants were seen in the context of the environment, and structural adaptations to habitats were stressed as a means to identify the plant. Along with plant identification, successional changes in the environment were stressed as well as the roles organisms play in those changes. Instead of a typical expectation of memorizing names of common plants, the emphasis was on recognizing common features, traits and trends among taxonomically similar species. Adaptive features were pointed out along with the specific habitat of the plant. Distinctions were made between vascular and nonvascular plants in the context of habitat. Students made careful observations using microscope slides, plant parts, leaves, stems and roots (e.g., red clover as a common legume and Vermont state flower). They also relied on their text and short lectures when the majority of the class had similar questions. Students made fieldnotes in their lab journals and transferred any other notes they thought might be helpful. Notes were organized in their lab journals to use on the identification portion of the assessment. The unit continually stressed plant adaptation to the local environment and the relationships between plant taxonomic groups.

Students were expected to see how variation in form can result from small changes through time among related organisms. Change through time was a constant focus to allow students to make connections between organisms that seemed dissimilar at first but, upon closer observation, had important similarities [Box elder (*Acer negundo*), red maple (*Acer rubrum*), and sugar maple (*Acer saccharinum*) are prime examples]. Student perception of the differences between related species helped to reinforce the notion that evolutionary change can result in speciation. Evolution was shown to be a process that has happened to populations and species in the student's own neighborhood, not just in far off islands or exotic species.

Conclusion: Dealing with Student Impressions, Perconceptions, and Misconceptions

Students face many challenges in comprehending the meaning and mechanisms of evolution. While most will readily admit that they can see that organisms have changed, and some have even gone extinct, many are left with few answers to the questions of how these changes occur and may, therefore, look to purposeful or deity-driven explanations. These can be summed up as ecological, religious, textbook treatment, and Lamarckian misconceptions similar to the treatment in Zuzovsky (1994). The concept of human as a product of a random, "uncaring" nature is difficult for many people to accept and has several proponents in the scientific community. While little research has been done recently to help teachers figure out the reasons for the problems students have in learning about evolution, there are several suggestions in the literature. Recent studies (e.g. Scharmann 1993, also Smith and Scharmann 1999) cite developmental issues of students at high school age that influence their ability to learn these concepts. However, this work does not explain the difficulty adults have with accepting evolution (Moore 1998a). Several such misconceptions return to the idea that humankind is somehow apart from nature and this may lead to many of the problems where religion is seen in conflict with science (Aguillard 1999). Many students are not yet capable of seeing the different roles religion and science play in our lives.

i. Lamarckian Misconceptions

Some students use Lamarckian principles to explain evolutionary mechanisms (Zuzovsky 1994). The ideas of "need" and "desire" to change seem to fit anthropomorphic ideas of nature in young students. Also distinctions between acquired and genetic traits are confusing to high school students; even after topics of genetics and evolution have been covered (Settlage 1994). Students may see evolutionary change as responding to a purpose (Moore 1998a). This "purpose" may come from their perception that an organism "needs" to change in order to survive (e.g., like growing thicker fur in the winter or deciduous trees dropping their leaves in response to the season). Their perception of purpose may come from an assumed need to improve, whether innate or from a deity.

ii. Ecological Misconceptions

Another type of misconception is the failure to notice how organisms interact with one another (Zuzovsky 1994). Seldom do students recognize the interdependence of life and, hence, the role humans have played in environmental changes. Students often can give a list of environmental concerns and their causes, but they seldom go beyond those publicly viewed popular causes and the special interests with successful organizations. Many cannot think of significant ways to lessen their own impact on the environment or, if they can, they do not take action. For example, people in the northeast have had serious problems sustaining any type of recycling or reduction campaigns in the past and students tend not to connect their actions with a bigger picture. Students seldom have the experience to see how environments change over time. They tend to see communities as if they do not undergo succession or disturbance.

iii. Religious Misconceptions

Students often have difficulty with the distinction between religion and science. They seem to feel both are competing ways to explain that which is unknown to them. They have been brought up to accept information provided in schools by teachers, on faith in many cases. And during the high school years, when they are asked to become skeptical scientific thinkers, it may be easier to discount the evidence behind legitimate scientific claims than checking out the validity and rigor of the scientific study in question. It may be helpful for them to know that many scientists are religious and that understanding evolution is not a question of faith, but a method of explaining the evidence based on observations of the natural world.

iv. Textbook Treatment:

The manner in which textbooks treat evolution as a separate set of facts rather than an underlying theme leads many students to feel it is a separate topic. Few texts incorporate hands-on inquiries in the section on evolution (Platt 1999). This may lead students to feel the topic is boring and not "real" science. High school students seldom focus on the nature of science as a dynamic field with ideas being challenged everyday. They often only see science as memorization or labs. Textbooks often contribute to the notion of science as bits and pieces rather than a process and body of knowledge (Nelson 1999). This contributes to the misconception that evolution is not really a part of biology or that it complies to a different standard than other topics (Rudolph and Stewart 1998). Nelson (1999) wrote that "according to both analyses (TIMSS, 1996 and AAAS, 1993), U.S. textbooks lack focus and coherence and rarely provide teachers with effective instructional strategies to help students learn specific content." Many publishers quickly respond to public demand by altering texts without regard to scientific consensus. In the 1920's textbooks dropped or altered evolutionary content in response to the Scopes Trial (Moore 1998b). This practice continues today.

v. Summary:

The misconceptions students have regarding evolution are the result of many factors in their lives and may be very difficult to overcome. According to Pearsall, Skipper, and Mintzes. (1997) "...students often fail to understand central concepts in the natural sciences despite the best efforts of good teachers". At St. Johnsbury Academy, the use of a change through time approach helped to alleviate these issues as the students had a coherent framework for the material covered. By bridging the units with long-term projects and frequently referring to the underlying theme, students were able to see science as a process of discovery and often debate. Students saw more than static facts and either/or questions in the units and were able to build their own concepts of evolution and science based on historical knowledge. They saw themselves as scientists rather than only learners. The text was treated as a resource, not as infallible treatise; the historical figures were seen as humans contributing to humanity's body of knowledge about the natural world, not as unquestionable icons. Religion was seen as a part of many scientists lives (particularly Darwin), sometimes in conflict, sometimes as an important component of their lives that enabled them to question and debate other's ideas.

Misconceptions of ecological and Lamarckian types were addressed by showing the connection of adaptation and habitat in populations. Humans as part of nature and continued emphasis on passing on of genetic, not acquired, traits helped students to see that Lamarckian evolution was a starting point and not a satisfactory conclusion to the puzzle of evolutionary mechanisms.

The thematic approach seemed to help students enjoy biology and make connections better than the topical approach I have used in the past. I intend to try a very similar approach in the future with modifications to units and content as determined by Academy departmental standards and results of Vermont standards testing. As a teacher, I have been quite pleased with the content coverage and feel that this approach gave students a much better feel for science as a process rather than a list of facts to memorize. The consistent return to topics and activities that students had done earlier in the year allowed a degree of reflection that I had not seen in previous years. I feel that the students had a much improved sense of biology as an interconnected whole rather than merely a group of topics covered in class. Evolution ties the discipline together in ways that help students make sense of the vast field that is biology.

Table 2.1. Numbers of Students Attending St. Johnsbury Academy from Each of the Sending Towns: 1998-1999.

Vermont Towns:		New Hampshire Towns:	
Barnet	110	Bath	6
Burke	10	Franconia	3
Danville	3	Monroe	43
Guildhall	8		
Kirby	5		
Lunenburg	22		
Lyndon	22		
Peacham	27		
St. Johnsbury	374		
Sheffield	13		
Sutton	4		
Walden	12		
Waterford	64		

Total Day Student Enrollment 1998-1999: 726

Table 2.2. Resident Student's Home Country or State 1998-1999.

Bermuda:	9	United States:		41
Brazil:	6		California	8
Canada:	1		Connecticut:	2
China:	1		Florida:	2
Germany:	7		Indiana:	1
Korea:	12		Illinois:	4
Hong Kong:	18		Massachusetts:	3
Indonesia:	4		Maryland:	1
Japan:	20		Minnesota:	1
Mexico:	4		Missouri:	1
Philippines:	1		New Hampshire:	1
Russia:	5		New York:	1
Saudi Arabia:	6		North Carolina:	2
Spain:	3		Ohio:	1
State Department:	3		Pennsylvania:	2
Taiwan:	4		South Carolina:	2
Thailand:	7		Tennessee:	1
Venezuela:	1		Vermont:	6
			West Virginia:	1

Total Outside the United States: 112

Total Resident Students 1998-1999: 153

Table 2.3. Examples of Popular Books by Reputable Scientists that Students Read for Discussion and Background in Evolution:

Author:	Title (abbreviated where common)
Stephen Jay Gould:	*Time's Arrow*
	Wonderful Life
	Full House
Niles Eldridge	*The Pattern of Evolution*
Ernst Mayr	*One Long Argument*
Richard Dawkins	*The Blind Watchmaker*
	Climbing Mount Improbable
	The Selfish Gene
Charles Darwin	*The Origins of Species*
	The Descent of Man
	The Voyage of the Beagle
David Attenborough	*The Secret Life of Plants*
	The Trials of Life
Richard E. Leakey	*The Making of Mankind*
Richard Fortey	*Life: A Natural History of The First Four Billion Years of Life on Earth*
Edward O. Wilson	*The Diversity of Life*
Richard Lewin	*Bones of Contention*
Jared Diamond	*The Third Monkey*
Jonathan Weiner	*The Beak of the Finch*

Table 2.4. Evidence Presented for Evolution:

DARWIN'S PREDECESSORS:	
Greek philosophers	Early notions of species change
Lamarck	Lamarkain Evolution search for a mechanism
Hutton	The Earth changes Uniformitarianism, old earth
DARWIN'S CONTEMPORARIES:	
Lyell	w/ Hutton: Gradualism old earth
Malthus	more are born than can survive
Wallace	natural selection theory
Couvier/Agassiz	Catastrophism and Creation doctrines
MECHANISTIC CONTROVERSIES:	
Genetic Drift	random change without pressure
Punctuated Equilibrium (Gould and Eldridge)	Stability and rapid change
PHYSICAL EVIDENCE:	
Structural	homologous structures and vestigial organs show the relatedness of species
Biochemical	the common pathways of energy systems and protein synthesis show relatedness
Fossil	show species change, ecosystems change, and many species both similar to today's and vastly different have gone extinct
Geological	The earth is very old, it has changed and environments have changed

Chapter 3

Student Attitudes and Understandings

To assess student attitudes concerning issues in the biological sciences, pre- and post-tests were given to students during the 1998-1999 academic year. The questions were designed to address a range of current topics and to evaluate changes in student attitudes after taking the course. The presurvey allowed these changes to be documented and measured and gave the students an overview of the biology course content.

Methods and Procedures

The test (Appendix 2 A, 2 B) was designed to measure student attitudes and knowledge in the areas of evolution, ecology, and biotechnology. Students responded to eight essay questions (Appendix 2 A) designed to measure content and depth of knowledge. The essay questions were evaluated according to a scoring rubric (scale of 1-5) and also by category of response. Rubrics were designed to test both misconceptions and depth of response (Appendix 2 C). Students also responded to fourteen questions (Appendix 2 B) based on how informed they were and the degree to which they felt an issue was of concern. A Likert scale from 1-5 was used and the scores on the Likert scale were averaged and compared for statistically significant changes in these attitudes. Students' current state of comfort with their knowledge of the issues was measured by having them complete a section asking if they would like more information about the issue. These questions were designed to test students eagerness to delve deeper into issues that typically are just surveyed in an introductory high school biology class. The results were tabulated and compared by percentage as pre-test and post-test measures of interest in areas of biology.

The attitudes section was scored on a Likert scale of 1-5. A response of one indicated that the student did not view the issue as a major concern at this time. A score of 3 (neutral) represented the student view that the issue was an area of some concern but not an emergency situation. A response of 5 represented the student view that the issue was of major concern and needed immediate or emergency action by citizens or government groups. Scores for each question were averaged and compared by Mann-Whitney U-test for significant changes ($p < 0.05$).

The pre-test (Appendix 2 A, 2 B) was administered to thirty-seven students on September 11, 1998, one week after the first full class of the new school year. Introductory material covered to this point in class detailed class policies and procedural issues such as formats for lab reports and grading. Content covered at this time was an overview of the nature of science and the topics in the field of biology. The students were given no instructions for the pre-test other than that its purpose was to help me collect data for a personal project and that the information would be used to help me improve my teaching methods. Students were given twenty minutes of class time to respond and were allowed more time if needed. Credit was given on their daily performance grade and 5 points extra credit was given on the first test of the quarter.

The post-test was administered on June 3, 1999 after students had finished their final assessment project. Fifteen minutes of class time were devoted to the post-test with the option for more time. Several students asked to finish outside of class and were given permission to return the post-test later in the day. Twenty three post-tests were returned and of those, 21 were from students who had also taken the pre-test. Three students did not return the second page of the post-test and one student only responded to the first three Likert questions. Two of the students who returned the post-test were not in the class on September 11.

All responses were reviewed after the school year had ended and in no way affected student's grades other than extra points that were given for returning the tests. This also ensured the tests remained as objective as possible; I did not teach to the test nor try to fill in specific student weaknesses on the pre-test prior to the post-test. The pre-test did not specify any length of response nor did I indicate when giving the tests that one type or length of answer was preferable. I spent the time after handing out the test observing from outside the class room through a large window. Students returned the tests independently to the front table when they were finished.

Attitudinal Likert responses were summarized in a spreadsheet and analyzed by *GB Stats* program using a Mann-Whitney U-test. Rubric scores for essay responses were tabulated on Microsoft Excel spreadsheets and also analyzed by *GB Stats* program. Informational (A/B) and essay category results were compared by percent change. Tables from Witte and Witte (1997) were used to assess significance of U or z scores (where cases were > 20). The essays were scored using rubrics one question at a time (Appendix 2 C). Short essay questions called for a different type of response and were designed to test depth of response (such as more detail knowledge or increased use of examples). While these questions called for more time to write an answer they were also designed for short responses. The rubric scaled responses from 0 to 5. Zero on the low end represented no attempt at an answer, and 1 was an attempt that did not answer the question. Scores from 2 to 4 showed increasing depth and knowledge. A score of 5 indicated clear content knowledge with specific examples or evidence. Analysis of the categories of response to the essay questions was designed to show depth and clarity as well as sorting types of misconceptions. The categories were designed to group answers of similar type and detail. Throughout the course, the students were required to craft essay type answers to homework as well as exam questions. Their responses were expected to show increased writing ability as well as increased content knowledge. The essay questions were grouped by general topic and student responses were categorized. The percentage of students responding in each category was calculated and compared from pre-test to post-test. The scale ranged from no response (0) to a detailed response clearly showing understanding of the nature and current views of the topic (5). The essay questions were also analyzed by category of response to determine type of response and potential misconceptions still held by the students (Appendix 2 D).

Results and Discussion

i. Attitude Questions

Responses for all the attitude questions varied from 1-5 on both pre- and post-tests. The overall average of the attitude questions changed from 3.60 to 3.63 which was not a significant change. The student attitudes did not change overall as a result of the course. The average response for questions 3,4,5,11,12 increased (Table 3.1) indicating greater concern, but none increased significantly. The average response for questions 1,2,6,7,9,10,13,14 decreased. The change for question 6 decreased significantly ($p<0.05$).

The only question which showed significant change in the averaged response was the question concerning the scientific knowledge of the public (question 8). Initial student responses were slightly above neutral, $x=3.15$. On the post-test the average score rose to 3.90 showing statistically significant increase in the type of response ($p<0.05$).

The lack of significant change could have been influenced by the timing of the pre and post-tests. Giving the pre-test during the very beginning of the school year may have pressed students to respond more favorably than they would have normally to questions of concern and information. Giving the post-test on the final day of the year, while offering maximal exposure to the course and allowing the concepts from the final assessment project to be formulated, may have caused the students to feel rushed or to be in a "vacation frame of mind." Perhaps the lack of responses to the A/B request for information on the post-test reflects a general fatigue with school rather than a lack of concern for the issues. Of course, it also is possible that the structure of the course had little influence in the areas surveyed or that students entered the course with a high level of background knowledge.

ii. Short Answer Knowledge Questions

The overall pattern of pre-test scores showed students to have a relatively high background knowledge, as would be expected for accelerated students. At the end of the school year, there were significant increases in accuracy of responses for questions three and eight compared to the pre-test (question three with a $z=3.48$, question eight with a $z=3.14$). Question 3 asked "what is cancer" and Question 8 asked "Do you know of any evidence of how populations change". The increase in response level for question 3 showed a decrease in misconceptions concerning an issue often in the media. Question 8 had less media coverage and showed an increased level of content knowledge. Both questions had many fewer responses below two on the post-test. Question 3 changed from 14 responses ≤ 2 to 2 responses ≤ 2 and question 8 changed from 19 responses ≤ 2 to 6 responses ≤ 2. Moreover, more students attempted to answer question eight (seven versus three scores of zero on the post test).

Changes in Depth of Response

i. Evolution Group

The first general category of evolution included questions one, two, six, and eight. There was little change in the ability of students to define evolution. There was a very slight increase (from 57 to 61percent) for the number of students including natural selection in their responses. The number of students including the misconception of evolution as progression decreased from 33 to 28 percent. Students improved on question two, providing a term that meant the opposite of evolution. The percentage responding with answers such as "no change" increased from 14 to 33 percent; the percentage responding with religious references stayed about the same (5 to 6 percent); those responding with "regression" category answers fell slightly from 33 to 28 percent. The number of students who gave no response decreased by 32 percent. “Other” type responses ranged from “disturbance” to “catatrophism”. One student responded with “Mendelian genetics”, which would result in little or no overall change in a population since allele frequencies stay the same.

Question six, evidences of change in the earth, showed a decrease in the “no response” category from 33 to 6 percent and an increase in the percentage responding with long term earth changes, such as erosion and climatic change, (up from 33 to 61 percent). The percentage of students giving examples of short term changes that they may have experienced (such as storm damage, volcanoes, or earthquakes) rather than analyzed evidence for dropped from 29 to 0 percent . The percentage of students including references to the influences these changes might have on organisms increased from 0 to 11 percent for question six, showing two students had an increased awareness of the biological impact geological change may create. One student gave evidence such as carbon dating and diversity without clear reference to specific changes in the earth.

Question eight asked for evidence of changes in populations. The change in response here was dramatic as shown by the statistically significant ($p<0.05$) change in rubric scores. The change from no response on the pre-test to the post-test dropped form 43 to 11 percent and the responses of simply “yes” increased from 5 to 17 percent. The more obvious answers such as changes in population size and extinction dropped from 33 to 28 percent while higher level responses such as citing population changes due to stress and competition increased from 10 to 33 percent. The category which students included mutations as a mechanism of change in populations increased from 0 to 17 percent.

ii. Biotechnology Questions

Questions three and five required knowledge of recent discoveries that include the use of biotechnology. Responses to question three “what is cancer” varied from the misconception that cancer is an outside “invader” such as a virus, to showing understanding that cancer is the mutation of a cell's DNA. The misconception that cancer is an outside agent decreased from 24 to 6 percent, simple reference to cancer as a disease dropped from 48 to 11 percent. A major change occured in the recognition of cancer as a change in the cells of the body, this category increased from 19 to 72 percent. Recognition of cancer as a mutation in the DNA was the same (one student).

Student knowledge related to cloning improved. In response to question five "what is cloning" responses changed from 52 percent originally answering merely a "copy" to only 28 percent on the post-test. Responses in the category of a genetic copy with the same genotype increased from 48 to 67 percent. No students elaborated with recent examples of cloning or the potential benefits or risks.

iii. Ecology Questions

Ecology was the theme for questions four and seven. Response categories were based on the types and levels of interactions discussed. Question four asked "what is ecology". The responses ranged from study of the earth or environment which dropped from 57 to 50 percent, a study of systems which increased from 19 to 28 percent, and the interactions of organisms either with each other or their environment decreased from 24 to 17 percent. Question seven asked about energy for the human body. The simplistic response of "food" dropped from 67 to 56 percent; mentioning organic compounds used by the body for energy increased from 14 to 22 percent. Mention of "respiration" dropped from 19 to 11 percent while responses that included mention of the sun or food web structure increased from 0 to 6 percent.

The Likert survey showed that as a result of taking the class, the students did not significantly increase their concern for the issues presented. The overall average for the class rose form 3.60 to 3.63, not a significant amount to show increased commitment to a course of action. The only other question that did not elicit a neutral response was related to dissection. Students felt that it was on the "not a major concern" side of neutral (about 2.6) despite several students adding comments that biology classes "should do it". Only 24 percent felt that the topic "needed immediate action" on either the pre-test or post-test. In class, students dissected earthworms, grasshoppers and fetal pigs, and they had recently finished the pig at the time the post-test was given. Like many schools, the department is looking into alternatives, but we have not reached consensus on an acceptable substitute at this time. The only Likert question to show a significant change was the concern with the scientific knowledge of the public which increased from 3.15 to 3.90 ($p > .05$, $z = 2.40$). This shows an increase in the concern students had for the ability of general public to make key decisions on issues.

The essay questions suggest that the percentage of students demonstrating increased depth of response or fewer misconceptions increased. The question concerning cancer showed a significant increase in response level when scored with the rubric and also a large increase in percentage (19 to 72 percent) of students understanding that cancer is the result of changes in the body's own cells and not the result of a virus or outside invader (decrease from 24 to 6 percent). Question eight showed significant increases in the percentage of students able to respond to the question. The "no response" category dropped from 43 to 11 percent and the understanding that populations change as a result of genetic mutations or variation increased from 0 to 17 percent. Population changes as a result of stress or competition responses increased from 10 to 33 percent as well. Students clearly felt more competent in their understanding of how populations change at the end of the class compared to the beginning. Other questions showed decreases in the percentage of students with misconceptions. The percentage of responses citing progress as a component of evolution only dropped form 33 to 28 percent but in other questions students were more likely to understand that evolution is change and that lack of change is a preferred response to the question of opposites (14 to 33 percent). There was a large percentage of students who understood that long term changes occur on the earth, showing an increase in knowledge of geological processes.

Conclusions

i. Putting the Theme into Practice

It was interesting to see the number of students who held onto "naive explanations" (e.g., see Settlage 1994) despite the material covered in class. All of these topics were discussed at length and recurred many times throughout the year. The data show that some misconceptions were decreased and many students showed increased understanding based on their responses to the questions on the post-test. When students are allowed to understand biology as a conceptual whole with a unifying theme of evolution, they seem to dispel many of their misconceptions and increase the depth with which they understand biological concepts. There has been a noticeable decrease in the number of students asking why biology is important and hopefully an increase in the awareness of the role the biological sciences play in their lives. Only one student this year indicated that because she was more interested in history and English, that biology was less important to her future.

The goals of the project were to see if teaching biology using a unified approach with topics based on the concept of how organisms change over time had and effect on the interests, attitudes, and depth of response of students. While responses to some of the questions did not change significantly over the course of the year, the students seemed to enjoy the course more than when the course was text driven. While this was not a defined student outcome it was gratifying to note. Perhaps some of the lack of significant change was the result of giving the post-test on the final day, perhaps some from the high level of interest the students had throughout the year in these issues. Despite the lack of significant results, I feel that the students came away from the course with a much better view of the nature of science and the way in which evolutionary change connects all organisms. I am currently searching for a better way to assess these changes. The search for patterns in natural sciences is tied to an understanding of how evolution shows relationships and explains common features.

ii. What Misconceptions Remain?

Several misconceptions continue to be difficult to overcome. One is the notion of evolution as progress. Perhaps this is tied to the historical or religious idea of man as the end product of evolution. Some students may see evolution as a stairway and each species as a stepping stone to increasing complexity. The notion of population changes as short term responses to environmental or predation pressures remained, despite discussion of population dynamics to show how populations can reach equilibrium or steady states if given time. However, the understanding that genetics are key to the changes in populations did increase.

iii. What Are the Next Steps?

The use of evolution as central concept unifying biology needs to be further expanded into all activities in the curriculum at St. Johnsbury Academy. The start made this year in many areas, especially regarding the role of evolution in national standards is an important focal point for teachers.While the search for effective asssessment tools continues. This project has given us the opportunity to change from a topical approach to a unified thematic approach that meets the standards for biological content as well as giving students a broad base understanding of how living systems work. This approach will allow the students to make intelligent choices regarding the challenges humans have ahead to keep the natural world as diverse and biologically rich for their children as possible in the years to come.

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Appendix I.

Example Activities

Activity 1: "How Big is a Leaf?"

teacher actions:	student actions:
1. Give students open-ended question	narrow question down to manageable, specific question e.g. "big" means length and width; What kind of leaf?
2. Use resources and experiences to make hypothesis	discuss and reach consensus within lab group as to reasonable expected results e.g. a sugar maple leaf is 25 cm long and 20 cm wide, a leaf is very thin so we are not concerned with volume
3. Use hypothesis to outline procedures	determine best way to measure leaf "bigness" since we are dealing with length and width we need to measure a maple leaf with a ruler- maybe it is better to measure several leaves since I have seen leaves of different sizes - 10 sounds reasonable (may be opportunity for a quick lesson on statistics and the value of random leaf choice)
4. Assign students to gather leaves and record location of leaf on tree number or letter each leaf so it can be identified later and store in ziplock-type bag so they won't dry out	students discuss who will gather leaves and how to keep them safe until class later that afternoon or evening: students gather leaves and record data and store leaves
5. Set up drying oven, rulers, string, electronic balance, graph paper, and any other materials students may need for measurements	students bring leaves to class and assign jobs for measuring, also discuss any new ideas they had to better answer the question (area?)
6. Check for student involvement, and group progress, discuss new ideas, if it does not come up suggest % H_2O, if needed give instruction on use of balance (esp. tare), explain use of drying oven and appropriate temperature (35-40° C)	measure leaves, record data discuss new ideas, find and record mass of each leaf and spread the leaves in the drying oven racks
7. After class: Check oven often to ensure maintenance of temperature	Write up procedures and organize length and width data into chart and graph form
8. Turn off oven before class, check leaves check data charts and graphs, help ensure students get their own leaves	collect their leaves- they will look much different, find and record new mass of each leaf

9. Show how to calculate % H_2O	groups work on calculations
10. Have students write their averages on board as long as each group used the same number of leaves each average carries the same weight	a group member writes averages on board while others record other groups' averages and check for mistakes calculate class average
11. Assign "finished lab report" following assigned format	check and fill in missing procedural steps: is everything we did listed?, organize data find average length, width, % H_2O and look for patterns in leaf size or % H_2O from data charts and graphs, write discussion section of report briefly (one sentence) outline what was done, what they found, ("We found the size of a sugar maple leaf to be...") and what it means, discuss ways to improve your procedure or "answer" so it is more likely to agree with others' (range?) or field guides if they wish -be careful to stress validity of their response given your environmental conditions.
12. Collect lab journals and correct for proper format and data check discussion for helpful suggestions and misconceptions	hand in lab journals for assessment along with participation grades.
13. Discuss any misconceptions that were found in assessing the labs and return journals	look over lab journals with group look for ways to improve offer suggestions to others regarding misconceptions
14. Return to data, format or procedural steps often in the remainder of the year remember students have data handy in lab journals	learn from others' suggestions, voice any suggestions of your own Don't lose lab journal keep it safe and. readily available.

Activity 2: The Discussion of Mechanisms of Evolution.

henslow estates
342 Abbey Road
London, England
Great Britain
March 23/24, 1865

My Dear Sir,

Please allow me the honor of requesting your presence at a cordial discussion of the preeminent topic in the current realm of the Natural Sciences; the mechanisms of the appearance and perseverance of favoured races in the struggle for existence. A debate covering the means by which said varieties of specific forms arise upon our planet will be convened in the Streeter Room of the Crystal Palace on March the twenty-sixth, this eighteen hundred and sixty-fifth year of Our Lord. The topic of discussion shall center upon the development and perpetuation of the recently discovered and wondrous animal called the Giraffe in the wilds of the African continental territories. The object of this discourse shall be the allowance of disparate and perhaps antithetical hypotheses to be heard and dispersed to the winds of public opinion. Open and public debate being esteemed as an infinitely valuable forum for the development and defense of cherished scientific ideologies amoung peers. The humble organizers of this happy gathering shall be ever in your debt for the favour of your presence at this gala event. While all present are gentlemen of the highest breeding and scientific reputation please come armed to battle in the arena of theoretical discourse.

Yours very sincerely,

J.S. Henslow, esq.

Assessment:

Score Sheet for Evolution Debate

1. Knowledge of character's role in the development of evolutionary theory.	15 pts.	_______
2. Ability to represent character faithfully.	15 pts	_______
3. Persuasive ability	15 pts	_______
4. Use of biological evidence to back up statements	25 pts	_______
5. Respectful demeanor to other characters	15 pts	_______
6. Overall summation of character's views	10 pts	_______
7. Extra props that enliven or add to presentation of views	5 pts	_______

Activity 3: FINAL ASSESSMENT

BIOLOGY ACC.
MR. LANGMAID
MAY ,1999

Here is your list for the final assessment- you are expected to be able to identify all these plants . The test will consist of identifying 10 of the following plants. They will be labeled for your identification. You will then spend the other assessment period writing a lab report in which you identify any adaptations these plants have made to life in their environment. You must therefore identify the habitat of each plant, the type of stem it has, the type of leaves, the size of the plant, and how its structure relates to its basic function.

sensitive fern (Onoclea)
bracken fern(Pteridium)
moss (Bryophyta)
interrupted fern(Osmunda)
raspberry (Rubus)
morning glory-bindweed (Convolvulus)
blackberry(Rubus)
brome grass (Bromus)
fescue(Festuca)
red clover (Trifolium)
buttercup (Ranunculus)
bedstraw (Galium)
mustard (Brasica)
burdock (Arctium)
dandelion (Taraxicum)
thistle (Cirsium)
gooseberry (Ribes)
rose (Rosa)
crown vetch (Coronilla))
Sweet clover (Melilotus)
Ground pine (Lycopodium)
horsetail (Equisetum arvense)
sourgrass (Oxalis)
Queen Anne's lace (Dacus carota)
common plantain (Plantago)
forget-me-not (Myosotis)
columbine (Aquilegia)
daisy(Chrysanthemum)
yarrow (Achillea)
cattail (Typhus)
skunk cabbage (Symplocarpus foetidus)

poison ivy (Rhus)
goldenrod (Solidago)
liverwort (Bryophyta)
speedwell (Veronica)
strawberry (Fragaria)
bluegrass (Poa)
sedge (Carex)
white clover (Trifolium)
wild cucumber (Echinocytis)
wild violets (Viola)
aster (aster)
curly dock (Rumex)
colt's foot (Petasites)
jewelweed / touch-me-not (Impatiens)
stonecrop (Sedum)
cinquefoil (Potentilla)
Alfalfa (Medicago)
scouring rush (Equisetum hymale)
milkweed (Asclepias)
ginger (Asarum)
mint (Mentha)
narrow-leaf platain (Plantago)
mullien (Verbascum)
ragweed (Ambrosia)
chicory (Cichorium)
lily-of-the-valley (Convalleria)

solomon's seal (Polygonatum)
wild grape (Vitus)
quinquefolia)
bloodroot (*Sanginaria*)
myrtle (*Vinca*)
yew (*Taxus*)
juniper (*Juniperus*)
white spruce (*Picea)*
red pine (*Pinus*)
fir (*Abies*)
white birch (*Betula*)
box elder (*Acer*)
red oak (*Quercus*)
quaking aspen (*Populus tremuloides*)
big tooth aspen (*Populus grandidentata*)
ash (*Fraxinus*)
choke cherry (*Prunus virginiana*)
apple (*Malus*)
staghorn sumac (*Rhus typhina*)
burning bush (*Euonymus*)
alder (*Alnus*)
knotweed (*Polygonum*)
white baneberry (*Actaea*)
basswood (*Tilia americana*)

trilluim (Trillium)
virginia creeper (Parthenosisus
celandine poppy (*Stylophorum*)
marsh marigold (*Caltha*)
white pine (*Pinus*)
blue spruce (*Picea*)
hemlock (*Tsuga*)
white cedar (*Thuja*)
yellow birch (*Betula*)
sugar maple (*Acer saccharum*)
beech (*Fagus*)
cottonwood (*Populus deltoides*)
rhododendron (*Rhododendron*)
black cherry (*Prunus serotina*)
willow (*Salix*)
hawthorne(*Crataegus*)
dogwood (*Cornus*)
elm (*Ulmus*)
lilac (*Syringa vulgaris*)
bedstraw (*Gallium*)
shepard's purse (*Capsella*)
maple-leaf viburnum (*Viburnum*)

During our time outside in the field it is your responsibility to;

1. identify the plant

2.describe the habitat (wet, damp, or dry-sunny or shady- flat or sloping - sandy or loam soil type)

3. size of mature plant

4. type of stem (woody or herbaceous)

5. leaf type, shape, and size (entire, toothed, or lobed: round, oval, heart, or palmate)

6. veination pattern (parallel or network)

7. reproductive structures (if present)

During our time inside you will organize your notes so that it will be easy for you to find the necessary description and information in the field.

You will be responsible for :

1. a well organized lab notebook containing:
   A. your field notes and
   B. your organized descriptions.

2. an accurate, defensible, identification.

3. a complete, well written lab report detailing your:

   A. purpose for doing the lab
   B. your procedures (how did you get the information, and what steps did you take in identifying the plants)
   C. your observations (field notes and descriptions of the plants you are asked to identify)
   D. your complete conclusion as outlined in #4.

4. Conclusion:

   A. were you able to accomplish your purpose? why or why not?

   B. What are the plants you identified ?

   C. How do you know? (what structures or characteristics enabled you to identify the plant?)

   D. And, using your knowledge of plants and evolution (from class notes and homework), how are these plants adapted to their habitat? What structures or characteristics are well suited for the environment the plant lives in? Is this plant highly evolved for life on land or is it similar to aquatic plants? In what ways?

How does this plant deal with the problems of:
   A. obtaining water?
   B. water loss?
   C. nutrient absorption?
   D. support for leaves?
   E. reproduction?
   F. seed dispersal?
   G. and most importantly for a plant the problem of obtaining and storing ENERGY?

FIELD SHEET

Plant #   common name   scientific name (genus)

______   ______________   ________________

characteristics

a______________

b______________

c______________

d______________

e____

______   ______________   ________________

characteristics

a______________

b______________

c______________

d______________

e____

Appendix II.

Pre-test, Essay Rubric, and Essay Categories

Appendix 2 A: Biology Pretest Essay Questions:

Name:
Date:
Period:

The following questions will give me a picture of your current biological knowledge. This will not be graded as a test but will be used to evaluate the course and my teaching. For you it will be opportunity to help improve the course and will be part of your daily performance grade.

1. Define evolution.

2. Give a term that means the opposite of evolution?

3. What is cancer?

4. What is ecology?

5. What is cloning?

6. Do you know of any evidence of a change in the Earth.

7. Where does your body's energy come from?

8. Do you know of any evidence of how populations of organisms change?

Appendix 2 B: Biology Pretest Likert Questions:

Name
Date
Period

How do you feel about the following topics:

	Not a major concern		Neutral		Immediate action required	I would like more information	I'm already well informed
Global warming	1	2	3	4	5	A	B
Logging old growth forests	1	2	3	4	5	A	B
Paper company's owning large tracts of land	1	2	3	4	5	A	B
Environmental extremists	1	2	3	4	5	A	B
Scientific knowledge of the public	1	2	3	4	5	A	B
Learning about evolution	1	2	3	4	5	A	B
Cloning living organisms	1	2	3	4	5	A	B
Genetic engineering	1	2	3	4	5	A	B
Human population growth	1	2	3	4	5	A	B
Ozone layer	1	2	3	4	5	A	B
Emission controls on cars	1	2	3	4	5	A	B
Dissection in science class	1	2	3	4	5	A	B
Air pollution	1	2	3	4	5	A	B
Water pollution	1	2	3	4	5	A	B

mod. C.A. Brewer, Univ. of Montana.

Appendix 2 C: Rubric for Pretest Essay Questions

Question #	0	1	2	3	4	5
1	no attempt	attempts but does not answer question	mentions change or Darwin	mentions change through time, with an incomplete example/ adapt ,fitness	change through time with a clear example	change through time with clear supporting evidence
2	"	"	mentions creationism or Bible regression/estinction devolution	mentions lack of change	uses terms like stability, equilibrium, or constant	uses terms and mentions time as element
3	"	"	a disease	disease of humans caused by carcinogens/ example	uncontrolled cell growth	uncontrolled cell growth caused by a change in a cell's DNA structure
4	"	"	a branch of biology study of 2 kinds of organisms "our house" ecosystems	interactions of two organisms or environment	interaction of organisms with each other and their environment	the study of the interactions of organisms with each other and their physical environment and example
5	"	"	mentions copying	making an exact copy of a human	genetic copy of any organism	genetic copy of any organism with example and possible benefits or dangers

Appendix 2 C: Questions 6-8

	0	1	2	3	4	5
6	"	"	yes:weather, storms, nat. disasters	cont. drift prior w/examples	specific examples and human impact	specific examples with biological impact
7	"	"	mentions food	discusses different food groups, oxygen	mentions groups and sources possible food chain connections	mentions sun and food chain sources of each food group
8	"	"	yes:size of individuals pop size	change with food source attempt example natural selection mutations	change with food source and predation example (n.s.) pred/prey	changes with environmental conditions and clear example

Appendix 2 D: Categories for Pretest Essay Questions

Type of Response

Question #	1.	2.	3.	4.	5.	6.
1	no response	Lamarckian/ need, wants acquired traits	describes as progression	change/time or natural selection	natural selection w/ examples such as Darwin's finches	other
2	"	Religion	Regression/ "devolution", or extinction	No Change stability equilibrium		other
3	"	Virus or outside invader	disease of humans	own body cells cell growth	DNA, mutation	other: weird cells that can kill, growth that eats away cells
4	"	study of earth or environment	Study of systems	Interactions between organisms/ environment		other
5	"	copy	genetic copy/ same genes	genetic copy with example/ opinion		other
6	"	yes	short term w/examples	long term w/ examples	influence on organisms	other: carbon dating/ diversity

Appendix 2 D: Questions 7-8

	1.	2.	3.	4.	5.	6.
7	no response	mentions food	organic compounds	respiration use of O2	plants/sun using respiration	others: sun/food web
8	"	yes	population size pred/prey, extinction	mutations, drift variation w/selection	comp/ stress, w/selection	other: apes>man

Appendix III.

Data

Appendix 3 A: Class averages for responses to Likert questions on pre-test and post-test. The scale ranged from 1 (not a concern) to 5 (immediate action required).

Question	Pre-test (n-21) Avg. Std. Dev.	Post-test (n=21) Avg. Std. Dev.
1. Global warming	3.65 (0.99)	3.63 (1.01)
2. Logging old growth	3.93 (0.92)	3.62 (1.02)
3. Large Tracts	3.43 (0.87)	3.85 (0.93)
4. Extremists	2.95 (1.10)	3.15 (1.14)
5. Knowledge of public	3.15 (0.88)	3.90 (0.85)
6. Evolution education	3.61 (0.86)	3.26 (0.81)
7. Cloning	3.33 (1.39)	3.05 (1.31)
8. Genetic engineering	3.16 (0.96)	3.32 (0.95)
9. Population growth	3.95 (1.24)	3.89 (1.05)
10. Ozone	4.29 (0.72)	4.00 (1.04)
11. Emission controls	3.28 (1.37)	4.05 (0.94)
12. Dissection	2.57 (1.63)	2.58 (0.57)
13. Air pollution	4.62 (0.67)	4.20 (1.01)
14. Water Pollution	4.55 (0.83)	4.25 (0.97)

Appendix 3 B: Responses to A-B questions. Answers ranged from A (Student would like more information on the topic), B (Student felt they were already well informed). Both A and B (Student felt well informed but would like more information) or no response.

Question		Pre-test (n-21)		Post-test (n=21)	
		Number	Percentage	Number	Percentage
1.	A	13	65%	10	50%
	B	5	25%	8	35%
	Both	0	0%	0	0%
	Neither	3	15%	3	15%
2.	A	10	50%	9	45%
	B	7	35%	10	50%
	Both	0	0%	0	0%
	Neither	4	20%	2	10%
3.	A	9	45%	6	30%
	B	6	30%	12	60%
	Both	0	0%	0	0%
	Neither	6	30%	3	15%
4.	A	14	70%	10	50%
	B	3	15%	7	35%
	Both	0	0%	0	0%
	Neither	4	20%	4	20%
5.	A	7	35%	7	35%
	B	6	30%	10	50%
	Both	0	0%	0	0%
	Neither	4	20%	4	20%
6.	A	9	45%	3	15%
	B	8	40%	12	60%
	Both	0	0%	0	0%
	Neither	4	20&	3	15%
7.	A	11	55%	12	60%
	B	6	30%	5	25%
	Both	0	0%	1	5%
	Neither	4	20%	3	15%
8.	A	15	75%	13	65%
	B	3	15%	4	20%
	Both	0	0%	1	5%
	Neither	3	15%	3	15%
9.	A	8	40%	5	25%
	B	7	35%	13	65%
	Both	0	0%	0	0%
	Neither	6	30%	3	15%

10.	A	10	50%	7	35%
	B	7	35%	10	50%
	Both	0	0%	0	0%
	Neither	4	20%	4	20%
11.	A	8	40%	10	50%
	B	6	30%	7	35%
	Both	0	0%	0	0%
	Neither	7	35%	4	20%
12.	A	8	40%	2	10%
	B	7	35%	14	80%
	Both	0	0%	1	5%
	Neither	6	30%	4	20%
13.	A	11	55%	7	35%
	B	7	35%	10	20%
	Both	0	0%	0	0%
	Neither	3	15%	4	20%
14.	A	11	55%	10	50%
	B	7	35%	7	35%
	Both	0	0%	0	0%
	Neither	3	15%	4	20%

Totals:	Pre-test			Post-test		
	A	144	49%	A	111	38%
	B	85	29%	B	132	45%
	Both	0	0%	Both	3	1%
	Neither	65	22%	Neither	48	16%